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**Designing Circuit Warz: enhancing teachers' and students' creativity through
problem-based games-based learning in the computer engineering classroom**

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Abstract

This paper argues that as students are increasingly digitally tethered to powerful, ‘always on’ mobile devices, new models of engagement and creative approaches to teaching and learning in engineering are required. Therefore, this paper explores the use of gamification and problem-based learning in an educational setting to increase student engagement and creativity. This paper provides a practical example of using game mechanics and demonstrates how a commercial game engine, in this case, Unity3D, can be used to create simulations to teach advanced electronic and electrical circuit theory. The Circuit Warz project is introduced and it is used to illustrate the ways in which engineering education might be reimaged to create engaging student learning experiences that are problem-centred and pedagogically sound.

Keywords: Problem-based learning, problem-based games-based learning, creativity, engineering, circuit theory, gamification

Designing Circuit Warz: enhancing teachers' and students' creativity through problem-based games-based learning in the computer engineering classroom

This paper explores the use of gamification and problem-based learning in an educational setting to increase student engagement and creativity. It offers an example of using game mechanics and problem-based learning to promote creative thinking while teaching advanced electronic and electrical circuit theory. Yet it is evident that across the globe Government agenda still focus on forms of digital governance, rather than creativity. Digital governance is the collecting and compiling of individual learner data in order to calculate and predict their future needs and to generate prescriptive learning through sophisticated software products (Williamson, 2014: 548). It is argued here that there needs to be a shift away from digital governance, towards increased creativity. The result will be a recognition that students need to bring all their learning capabilities to the classroom, rather than being required to leave their sophisticated abilities developed through networked publics behind, contained in some kind of hidden personal media scape. For example, students are making and creating opportunities and in arenas of which many staff are unaware. One example of this is ‘vidding’, whereby content is refashioned or recreated in order to present a different perspective, usually based on music videos and television programmes. The purpose of vidding is to critique, re-present and explore an aspect of the original media. Such an example of this is an Anime music video (AMV) that is usually fan made and comprises a range of clips from a variety of sources such films, songs and promotional trailers. These are amateur videos and are posted on sites such as YouTube and

AnimeMusicVideos.org. With the advent of networked media, interests can be supported by platforms such as LiveJournal, Tumblr, Pinterest, and sites can be devoted and designed for specific interest groups such as DeviantArt, Ravelry, or fantasy sports leagues (Ito et al 2013: 64). Yet, whilst vidding is a complex and highly skilled activity, with its sharing and learning considered important to those in the vidding community, it is not highly valued in other learning arenas. Yet higher education holds on to standards and performative practices which prevent and reduce creative learning possibilities. Quality, credit transfer and standards are all tightly bound within the current system and held on to by tenacious academics. Meanwhile students have, in the main, moved beyond such performative practices and bounded systems and instead use whatever apps, forums and sites that enable them to gain, create, recreate and repurpose knowledge. This paper argues that higher education needs to adopt creative approaches to teaching and learning that build on students' creativities from outside the classroom as well as gamification, problem-based learning and models of creativity. This paper suggests that the Circuit Warz project illustrates one way that engineering education has been developed to prompt creativity and criticality in engineering students. As a whole, games and gamification is a useful starting point to explore and develop creative pedagogies and creative skills for engineering students.

Games and gamification in higher education

There has been much debate about the relationship between games, learning games, and serious games. Serious games are seen as simulations of real-world events or processes designed

for the purpose of solving a problem. Thus their main purpose is to educate users; they have a clear educational purpose and are not intended to be played primarily for amusement. Epistemic games were developed by Collins and Ferguson (1993) who categorized them into structural analysis games, functional analysis games and process analysis games. The idea is that each type presents increasing levels of challenge, so that structural analysis games are the easiest and process analysis games the most difficult. In short:

1. Structural analysis games determine the components or elements of a system. Examples include making a list, creating a timeline, drawing a map or filling in a matrix.
2. Functional analysis games show how the elements in a system are related to each other. Examples include: creating a hierarchical chart, deriving an equation or making a causal chain diagram.
3. Process analysis games describe how a system behaves. Examples include: drawing a flowchart, creating a graph to show change in a system over time, creating a spreadsheet to project business profits.

Shaffer (2006), who built on this work, argued that epistemic games are simulations that link knowing and doing, His work focused on the use of epistemic games for professional practice, suggesting that reflective practice is an important component, which is also important for the development of the professional capabilities required of engineers. For Shaffer the premise of epistemic games should be on developing the values, skills, ethics and epistemology

that professionals use, to think in innovative ways. To date these concepts are often disregarded in games design and development. However, Newman (2004) argued that the world of computer games is messy and complex. He suggests that 7 ‘types’ can be delineated (p12), these being: action and adventure, driving and racing, first-person shooter, platform and puzzle, role playing, strategy and simulation, Sports and Beat-em-ups; whilst asserting that such categorization takes little account of the diversity and complexity of games, game designers and the notion of games. As Newman suggests, such delineation is rather nebulous and in recent years there has been a shift away from game typologies towards the purposes and complexities of games design.

Arnab et al (2015) argue for the importance of a model of games-based learning. The model proposed is the Learning Mechanics–Game Mechanics (LM-GM) model, which is a model that locates pre-defined game mechanics and pedagogical elements to be used in a game. Whilst this complex model is a very useful starting point, it tends to draw on older theories and models of learning, which have been superseded by newer ones that tend to take greater account of the ways in which young people and students learn in the 21st century. If this were to be developed by focusing on instantiations of problem-based learning that centre on critical pedagogy, rather than the outdated Bloom’s taxonomy (Bloom, 1956), it could help to shift current understandings of games-based learning away from linear, solid and content driven models of learning towards more creative approaches. However, it is vital to see games (serious and epistemic) through both their structure and the way in which modes of knowledge are located in the curriculum. By doing this, it will be possible to create games that increasingly move away from outcome-based models and instead creativity and uncertainty in learning.

Sherwood (1991) argues that games helped children to engage in ‘fundamental elements’ of the ‘new curriculum’, namely inquiry, creative expression, social interaction and cooperative effort. These would seem to be fundamental to learning whether at a school or in higher education. Yet, as Hamalainen et al (2006) suggest, there has been little research into collaborative learning games. There have also been few, if any, problem-based learning games that link strongly with models and theories of PBL. Further, there seems to be a lack of understanding about the difference between problem-based learning and problem-solving, which makes the landscape of problem-based learning and digital games-based learning rather murky. For example, Kiili (2005) illustrates this:

Generally, games provide a meaningful environment for problem-based learning. The ability to solve problems is one of the most important features of human skills (Holyoak, 1991). Thus, one goal of education is to groom students to encounter novel situations (Bruer, 1993). Problem solving can be regarded as striving toward a goal which is not immediately attainable. Games provide a meaningful framework for offering problems to students. In fact, a game itself is a big problem that is composed of smaller causally linked problems. The nature of challenges that constitute the problem can vary greatly. Generally, a problem can be anything that somehow restricts a player's progress in the game world.

(Kiili, 2005, p. 17)

What is also interesting about Kiili's argument is the importance of 'flow' in game play. He suggests 'Bad usability decreases the likelihood of experiencing task based flow because the player has to sacrifice attention and other cognitive resources to inappropriate activity' (Kiili, 2005: 15). Yet there is little sense throughout his article that experiencing disjunction is an important part of learning; about the game, oneself as a game player, and understanding though not necessarily achieving, the objectives of the game.

Developing Creativity through Gaming and Problem-based learning

One of the challenges of developing creativity in higher education is both how it is defined and how it is perceived and implemented in a given discipline. In the context of engineering education creativity is seen as something that is almost impossible to define. For example, Lui and Schonwetter (2004) and more recently Cropley (2015a) argue that engineers need creative minds to meet the needs of the engineering profession and suggest that teaching creativity can help students learn more about their own creative abilities. What is perhaps pertinent to note, as Cropley argues that creativity is very well defined, in general, but that disciplines such as engineering have been slow to adopt definitions from other disciplines like psychology, and continue to portray it as elusive and hard to define.

There have been suggestions that both PBL and creativity improve student engagement in learning. Trowler and Trowler's (2010) literature review recognised that student engagement has received extensive attention internationally and individual student learning dominates the evidence reported. In their review, definitions of student engagement are presented, which

include the extent to which students are engaging in activities that contribute towards desired (high-quality) learning outcomes. Zepke and Leach (2010) similarly focus on ‘high quality learning’ but broaden their accepted definition to include a focus on the student’s cognitive investment, active participation and emotional commitment to their learning. However, it would seem that many current definitions promote an institutional focus centred predominantly on outcomes such as retention and success rates (Kuh et al, 2007). Whilst Trowler and Trowler’s review of the student engagement literature identified the noticeable absence of the student voice, issues such as chaos and cosmos (Silen, 2000) and frame factors (Jacobsen, 1997) have been found to be central to enhancing learning and promoting student engagement in PBL. Student engagement remains a complex and contested concept that requires further consideration in problem-based learning and higher education in general. Yet it is argued here that combining PBL and games-based learning can encourage student engagement and facilitate the development of creativity which is vital for the engineering discipline.

In problem-based learning the focus is in organizing the curricular content around problem scenarios rather than subjects or disciplines. Students work in groups or teams to solve or manage these situations but they are not expected to acquire a predetermined series of ‘right answers’. Instead they are expected to engage with the complex situation presented to them and decide what information they need to learn and what skills they need to gain in order to manage the situation effectively. There are many different ways of implementing problem-based learning but the underlying philosophies associated with it as an approach are broadly more student-centred than those underpinning problem-solving learning. Since its inception in the 1980s PBL

has developed in diverse ways worldwide, yet there has been relatively little mapping of its theories, practice or disciplinary differences. This has led to confusion within the academic community about which constellation to adopt or what will be the best fit for a given curriculum. Merely to list specific and narrowly defined characteristics does not in fact untangle the philosophical conundrums of PBL. Further, PBL is an approach to learning that is affected by the structural and pedagogical environment into which it is placed, in terms of the discipline or subject, the tutors and the organization concerned. Whilst PBL is still undergoing a process of change worldwide, such change has been analysed by few in the field of higher education. In some areas, possibly in some engineering curricula, there is a sense of performative rules about how PBL should be used, but instead it would seem that we need pedagogically informed constellations of PBL.

The idea of locating different formulations of PBL as a series of constellations develops the idea that there is a broad range of PBL approaches, as in Table 1 below. The notion of constellations embraces the overlapping nature of differing PBL practices that relate to one another and intersect in particular configurations or patterns. The notion of constellations helps us to see that there are patterns not just within the types of PBL but across the different fields of practice (Savin-Baden, 2007). The idea of grouping PBL approaches in this way is drawn from Bernstein (1992), who argued for the use of constellations as ‘a juxtaposed rather than integrated cluster of changing elements that resist reduction to a common denominator, essential, core or generative first principle’. The use of constellations (rather than constellations per se) allows for the categorisation of PBL approaches according to: problem type, form of interaction, knowledge

focus (following Gibbons et al, 1994; Barnett, 2004 and Savin-Baden, 2008), form of facilitation, focus of assessment and learning emphasis. An important factor when considering the grouping of PBL practices in this way is the mode of knowledge that is to be designated as disciplinary knowledge.

Insert Table 1. Constellations of problem-based learning (Savin-Baden, 2014

For example, Terkowsky and Haertel (2013) suggest, based on the results of the German research project “Da Vinci – fostering creativity in higher education” 6 levels of creativity:

1. Self-reflective learning.
2. Independent learning.
3. Curiosity and motivation.
4. Learning by doing.
5. Multi-perspective thinking.
6. Reach for original ideas.

Terkowsky and Haertel (2013, n.p.) then suggest three consecutive problem levels to foster different facets of creativity, in Table 2, below:

Insert Table 2 Three consecutive learning levels, corresponding to the problem types and three facets of creativity

These levels have similarities to the problem types suggested for use in PBL by Schmidt

and Moust (2000), Table 3, who suggested a taxonomy for using problems in order to acquire different kinds of knowledge, rather than solving problems or covering subject matter. The importance of the work undertaken by Schmidt and Moust (2000) is not only the way they provide and explicate different problem types, but also their exploration of the way in which the questions asked of students guide the types of knowledge in which students engage.

Insert Table 3 Forms of knowledge and problems for PBL

Schmidt and Moust (2000) have argued that students acquire different categories of knowledge during their course of study and that diverse problem types will guide students towards these different categories. The way in which questions are asked of students guide the types of knowledge with which they engage. For example, the question “What is the matter with this man?” results in students seeking explanatory knowledge; knowledge that offers some reason for the symptoms the man is experiencing. Whereas if the students were asked, “What would you do if you were this man’s physiotherapist?” then the emphasis becomes one of action rather than explanation. The assumption is that the student always understands the explanatory knowledge and can take action, thereby using procedural knowledge. Such a distinction is important because it helps students to begin to understand how they recognise and use different types of knowledge. By enabling students to understand the differences between objective knowledge, personal knowledge and procedural knowledge they will develop criticality through being enabled to engage with troublesome knowledge. If, for example, students understand that

personal knowledge, representing people's attitudes and values, is more difficult to critique than objective knowledge, this will help them to see both the importance and challenges of their own moral perspectives on issues. By focussing on knowledge in the first year students learn how to manage the knowledge associated with explanatory problems and fact-finding problems. This is built on in Year 2 but strategy problems are also included. Then by introducing complex moral problems in the third year and combining the other types of problems from Table 3 it will be possible to develop students towards criticality. Furthermore, problems could also be of different lengths, types and be increasingly messy as the programme progresses, but instead of students engaging with several problems simultaneously they would engage with only one at a time and links and overlaps would be assured between consecutive problems. Also in the later part of the programme students would be able to meddle with the problems on offer, thus creating the possible option of wiki style problems. At the end of the article Terkowsky and Haertel (2013) ask a number of questions 3, of which are summarized here:

- What kind of education will be needed, if a society wants to bring up future inventors who are able to cope with the future problems?
- How can teachers be trained efficiently and successfully in creativity fostering techniques?
- How can creativity and interdisciplinary knowledge be fostered in engineering education courses and curricula?

We suggest that the use of game-based PBL that focuses on the higher PBL constellations (6-9) may offer answers to some of these questions and one such example is the Circuit Warz Project:

Problem-based games-based Learning: the Circuit Warz Project

The Serious Games and Virtual Worlds research team at the University of Ulster focus on the potential of virtual worlds and video games technologies for undergraduate and postgraduate teaching of electrical and electronic engineering related subjects (Callaghan., McCusker., Losada., Harkin and Wilson., 2013). The design used was problem-based and game-based, see Table 4, below). It is important to note that the term problem-based learning has been adopted here along with gamed-based since the authors recognize the value and flexibility of problem-based learning as an accommodating, adaptable and culturally relevant approach to learning. Yet there is relatively little understanding of the relationship between problem-based learning, game-based learning and the impact of these different constellations on student engagement and in improving learning. Combining the two approaches to design and learning fostered collaborative learning and engagement in ways that problem-solving approaches with fast solutions often do not. Thus the examples offered by authors using these combined terms illustrate a clear overlap and recognize the value of using role play, trial and error in learning as well as developing creativity, autonomy and engagement.

Insert Table 4 Problem-based Learning and Game-based Learning

Game based learning for engineering education

The Serious Games and Virtual Worlds research team at Ulster University focus on the potential of video games technologies for undergraduate teaching of electronic and electrical engineering related subjects. The Circuit Warz project was conceived to investigate if creating a compelling, engaging, immersive, collaborative and competitive environment to teach electronic circuit theory and principles would increase student engagement (Callaghan et al, 2009) To achieve this objective, it was first necessary to investigate how to create a game related to the biasing of electronic and electrical circuits. The core loop of the game is based on calculating/selecting the correct value(s) of individual circuit components e.g. resistors/capacitors, to generate a given circuit output/response based on a known value of input/stimulus provided as illustrated in Figure 1:

Insert Figure 1 Core game loop for Circuit Warz project

To determine the validity of the approach a game prototype was created based on the principles of positive feedback in operational amplifier oscillators and was initially modelled in Excel to fine tune core gameplay (Figure 2). Oscillators are astable devices that produce an alternating or pulsing output voltage which is primarily dependent on the values of resistor/capacitor combinations chosen. The game design approach taken was problem-based and presented the student with randomly generated output values/responses from the circuit i.e. peak

to peak voltage and period of the waveform, and the formulae to calculate these values. The student then has to compete against the clock to calculate and then select the individual component values from an existing bank of resistors/capacitors to create the correct combination(s) of components to provide the target output(s). To do this successfully the student needs to have a clear understanding of underlying circuit theory and its application. The score achieved is based on how close the value of actual output of the circuit (peak-peak voltage and waveform periods) is to the target output, where the scoring mechanism provides feedback to the student on their level of understanding of circuit theory, since there is a direct correlation between scores and the accuracy of results (Callaghan et al, 2013). The main learning outcomes are to explore and experiment with a range of different fundamental circuit components i.e. resistor and capacitor combinations, in order to understand the process of biasing an oscillator circuit to convert a DC source to AC output while computing specific output values (peak to peak voltage and waveform periods).

Insert Figure 2 Solve for $R1$, $R2$, $R3$, C to achieve target frequency and V_{pp}

Once the testing and tuning phase was complete the game was created and implemented using the Second Life virtual world simulator integrated with the Moodle virtual learning environment (VLE) through SLOODLE (Livingstone & Bloomfield, 2010). It is designed to be used as a supplementary teaching resource, complementing theoretical and practical material taught in the classroom and laboratory. The game scope and functionality was extended to

become a group undertaking using a collaborative/competitive multi-player framework with five teams comprised of four students each who need to work together to compete against the other teams in a series of time based challenges in an arena environment. The game/virtual world is linked to real hardware and the teams are working with actual physical circuits and as the values of the resistors and capacitors are changed in the virtual world these changes are replicated in the physical hardware through a switching matrix. Figure 3 shows the physical hardware backend which is comprised of an oscillator circuit with a range of resistors and capacitors, arranged in banks which can be individually selected using the switching matrix. The test instrumentation, including an oscilloscope and power supplies are accessed and controlled using GPIB. The circuit outputs are measured by physical test instrumentation and fed back into the virtual world. The management of the real hardware is facilitated using the SLOODLE architecture to integrate the physical oscillator circuit, test instrumentation and switching matrix. It also manages the entire process, facilitating communication and interaction between each of the physical components and the virtual world.

Insert Figure 3 Architecture of the physical hardware

The simulation created inside Second Life consists of the main arena where the game takes place and the learning zone. The learning zone is placed outside the main game arena and divided into four sections; registration, team creation, support material and quiz (Figure 4). Students register their avatar to partake in the game (1), then select a team to join and modify

their avatar to wear the team colours (2). The team creation and management process is facilitated using a modified version of Moodle/SLOODLE allowing the students to register their avatars inside Second Life and record this process back into the VLE. Additional subject based teaching resources are available for revision (3) in the learning zone. After this process is complete all the students/teams then undertake and complete a quiz based on the subject matter (4). The number of attempts the teams subsequently get in the arena during the game to solve the circuit puzzles are based on the number of correct answers achieved in the quiz.

Insert Figure 4 Learning zone and user/system management functionality

Team assessments are performed against the clock where the winners are the team that can work collaboratively to solve the problems presented by successfully applying circuit theory to select combinations of individual resistor/capacitor values to achieve the pre-defined circuit output(s) in the shortest time and with the highest level of accuracy. Each game lasts a maximum of three minutes and team members communicate with each other using in-world text chat and voice. The tutor/lecturer is also present/represented as an avatar inside Second Life to provide extra guidance and direction to the students as needed. When the teams enter the main game arena the game begins. Each team takes individual turns in sequence to solve the puzzles, where the game calls each team to the podium and provides unique/different target values for peak-peak voltage and the waveform period to calculate for each turn (Figure 5).

Insert Figure 5 Overview of game arena functionality and implementation in Second Life

When the team have decided which combination of components to select to bias the circuit the red button shown in Figure 5 is pressed. The physical circuit is then completed and the actual values achieved by the team are read back into the system and compared to the target values from which a score is provided. The final score given is based on combination of time taken and accuracy of the output value(s) achieved compared to the target values. Feedback on the biasing assessment exercises are displayed on the score boards shown inside the game (Figure 6). The team with the highest overall score wins and all student interactions in the VW are recorded back into SLOODLE for future assessment and review. Figure 6 provides an example of recorded assessment results for two teams.

Insert Figure 6 Game play arena, resistor/capacitor combinations/outputs and score in VLE

The combination of accuracy (actual output values achieved versus target values) and overall time taken to complete the circuit, which is used in the scoring mechanism and the visibility of the other teams' current scores allows a number of interesting team strategies to emerge. The teams can decide to use one of two main approaches to solving the circuit problems depending on their position in the overall leaderboard i.e. use more time to calculate the specific component values/combinations to get more accurate output values or use a "rule of

thumb"/heuristic approach to save time e.g. make informed guesses about relative values/combinations of resistors/resistor equivalents and their subsequent impact on output values. This gives the students more insight into the practicalities of biasing electronic circuit and of the different approaches they can take to create/solve circuits.

Initial evaluation

The evaluation process at this stage mainly focused on user acceptance of these types of environments as teaching platforms from both an educator and student perspective. The evaluation looked at the age profile of the student, their familiarity with communications technologies, social networking and video gaming, the technological learning curve involved and whether the 3D immersive environment\experience was engaging and whether it added or detracted from their experience. The overall feedback was positive. The cohort of students chosen for the evaluation phase were familiar with social networking and technology in general, and after a short learning curve readily accepted the game based VW as just another tool and complementary resource to add to their repertoire of learning resources, with minor reservations e.g. granularity of navigation controls and interactions. In summary the students enjoyed the collaborative group aspect of the project and the ability to interact with the simulations and visualize circuit theory/operation in new and interesting ways. In addition to this they felt strongly that the competitive team based element of the Circuit Warz project helped reinforce the theoretical material learnt as they had to practically apply this knowledge under time constraints while making strategic decisions related to overall team performance and ranking. The academic

staff involved in this stage of the evaluation were very positive about the potential this approach possessed once the initial learning curve was overcome. In particular, they felt the collaborative working facilities offered by the 3D immersive environment were useful and warranted the extra effort required to create the content. These academic staff members would generally be classified as ‘early adopters’ and by their very nature would be more open and responsive to embracing new technologies. Later evaluations would involve a more representative demographic of faculty academic staff.

From an overall perspective this technology is maturing rapidly and reaching the stage where it is sufficiently robust and reliable for wide scale deployment as an enhancement both to the Moodle platform and for adoption by the larger educator community. The main barriers to widespread adoption are educator awareness, the inherent learning curve, acceptance of the possible benefits of using these environments for teaching, and a willingness to explore innovative and non-standard technologies in educational practice. A careful balance is needed to ensure the use of the technology does not distract from the presentation of the subject material. In addition, the underlying technology needs to mature sufficiently to a point where adding a VW simulation or game based element to teaching material is as easy as adding additional content to a VLE. At an institutional level the barriers to the widespread adoption of both technologies for teaching are significant, mainly due to technological challenges and lack of understanding of what these platforms can offer to distance education students. For now it remains a minority activity.

Discussion Enhancing learning and creativity

There is a broad range of literature that has created models and typologies of creativity and suggested ideal capabilities engineers ‘should’ possess as well curricula to support the development of these capabilities. However, what is really needed is an understanding of the kinds of curricula that promote and enhance creativity (of all types) in students in ways that fit with diverse approaches to learning and stances towards knowledge. Much of the current engineering literature that discusses the importance of creativity seems to want to ‘fix’ creativity, to ‘make’ creative engineers, to ‘design’ creative curricula (for example, Mahaux., Nguyen., Mich, & Mavin, 2014). Whilst at one level this is laudable, such an approach tends to leave students’ learner identity at the door. What is needed instead is the development of curricula that prompt engagement with conceptual threshold crossing using constellations of problem-based learning to guide this process. Cropley (2015b; 2016) argues that engineering curricula still use traditional teaching approaches to teach traditional topics with few opportunities for the development of creativity. He also notes the results of a UK employment survey in the area of computer science and IT, (Bateman, 2013) indicates that graduates miss out on employment opportunities due to a lack of creativity. Cropley believes that rather than just restating the problem of the lack of nurturing creativity it is important to review the issues in a holistic way. In practice this means not merely adding in creativity to an engineering programme, but instead shifting away from a reductionist notion of science towards a systems model. Although this is one exemplary model we suggest a step further would be to begin with creativity as the central focus for learning in the curriculum, with a focus on 4 components of: Learner identity, PBL,

Epistemic games and Conceptual threshold crossing. Certainly the work by Haertel et al (2015) seem to suggest the need for courage. Thus we argue that not only do students need to do something unusual, as they suggest, but in fact the curriculum itself is both courageous and unusual in embracing pedagogy and enhancing learning around these four concepts:

Insert Figure 7 Creating a creative engineering curriculum

The constituents of our creative curriculum for engineering comprises four components:

Constellation 9: Problem-based learning for transformation and social reform

This form of PBL is one that seeks to provide for the students a kind of higher education that offers, within the curriculum, multiple models of action, knowledge, reasoning and reflection, along with opportunities for the students to challenge, evaluate and interrogate them. It embraces Pratt's notion of teaching for social reform (Pratt *et al*, 1988), in which effective teaching is designed to change society in substantive ways. Through this form of PBL, facilitators awaken students' embedded perspectives as well as the values and ideologies located in texts and common practices within their disciplines. Thus texts, in the broadest sense of the notion of 'texts', are interrogated for what is said and what is omitted; what is included and what is excluded, and students are encouraged to explore who and what is represented and omitted from dominant discourses. Thus programmes, modules and scenarios are designed in this constellation in such a way as to prompt students to examine the underlying structures and belief

systems implicit within a discipline or profession itself; in order not only to understand the disciplinary area but also its credence.

Conceptual threshold crossing

Literature concerning threshold concepts (Meyer and Land, 2006) concentrates on the identification of discipline specific concepts which are in a sense essential in the acquisition of the thinking, learning and communication of understanding within specific subject learning. For example, to think like an engineer, or to think, learn and express oneself like an historian. Developing understanding and use of these concepts is, it is argued, crucial for student learning and knowledge construction. Building on theories of threshold concepts developed in undergraduate disciplines, notions of conceptual thresholds have been developed to identify those moments at which students make ‘learning leaps’, develop their learner identity, and start to work at a critical, conceptual and creative level.

Learner identity

Learner identity encompasses positions which students take up in learning situations, whether consciously or unconsciously. There needs to be a recognition that learners need to be defined by more than just their learning styles. The concept of learning styles has suggested that an individual has a consistent approach to organizing information and processing it in the learning environment, yet this is troublesome and invariably not the case. Thus learner identity incorporates not just a sense of how one has come to be a learner in a given context, but also the

perceptions about when and how one actually learns. As a result, learner identity also encompasses affective components of learning that often seem of little matter to those in the business of creating learning environments in institutional settings. In developing learner identities, some students are enabled to shift beyond frameworks which are imposed by culture, validated through political agenda or supplied by academics. They are facilitated in developing for themselves, possibly through learning such as problem-based learning, the formulation of a learner identity that emerges from challenging the frameworks, rather than the imposition of the frameworks and systems upon them.

Epistemic games

Developed by Collins and Ferguson (1993) epistemic games have been categorized into structural analysis games, functional analysis games and process analysis games. However, recently Markauskaite et al (2014) provided a comprehensive overview of games for knowledge action, which is perhaps one of the most useful conceptualizations of epistemic games, summarized below:

Situated problem-solving games are played during the investigation and solution of specific professional problems, such as conducting reviews of medications used by patients with multiple diseases in order to identify possible issues, with an aim of proposing better medication plans (pharmacy), or designing lessons for classroom teaching (education).

Meta-professional discourse games are usually played with other professionals within a broader professional field, in order to evaluate various professional products, actions or events. They involve various deconstructions, evaluations and reflections, such as analyses of new medications, evaluations of teaching resources, and reflections on one's practices.

Translational public discourse games are played by professionals when they engage in interactions with people who broadly could be described as "clients".

Weaving games are played in dynamic action and involve continuous intertwining of meaning-making, social interaction and skilled performance. They range from very specialised games that can require fine-tuned physical skill - such as strategies for capturing all the spelling mistakes in a literacy test - to quite generic games that require complex coordination of various general and specialised strategies and skills

(Markauskaite et al, n.p. 2014)

This kind of curriculum model will ensure strong pedagogical foundations in the context of the new and emerging challenges of an overly performative educational system. However, we argue that the role of the university is to prepare students for a world in constant change, being exposed to several and sometimes conflicting frameworks for understanding. Students need to be able to continually renegotiate learning frameworks, structures, values and ideals. This type of

society with its emerging themes of ecological safety, the danger of losing control over scientific and technological innovations, and the growth of a more flexible labour force, is having a profound effect upon higher education. To date, there has been little research exploring the impact of different types of learning problems on students' experiences of learning, nor has there been much exploration of the use of diverse types of problem at different levels of a course. There is a need to recognise that curricula should be contestable and its assessment negotiable. Whilst such curricula would be seen by many as high risk, as long as robust assessment procedures are used that match the learning there is relatively little risk of students being a danger to themselves and others. Further, this form of curriculum creation can also encourage students to contest both knowledge and the relative status of diverse knowledges, thereby developing creativity. In summary what is needed is a constructivist curriculum in which students can be active, social and creative learners. It is this creativity and improvisation, this exploration of new and innovative spaces along with the sense of the in-between, which offers students new learning opportunities that transcend what they learn in social spaces and academic spaces. The success of this project to date indicates that active student engagement in learning is becoming an increasing priority for higher education. There have been a number of moves, in the UK at least, improving creativity and developing flexible pedagogies, and the Circuit Warz project supports these ideals. It is important that educators and practitioners shift away from simplistic benchmarking and overbearing standards that get in the way of creativity and deep engagement with learning. Problem-based and gamed-based learning open students up to ways

of thinking about knowledge differently. Engaging with games such as Circuit Warz can help students to stand inside and outside academic/personal worlds at the same time.

Conclusion

This paper has provided a brief overview of ongoing research at the School of Computing and Intelligent Systems, University of Ulster, Northern Ireland into the use of virtual worlds/games and virtual learning environments for teaching. The Circuit Warz project was introduced and a number of complex, highly interactive and engaging simulations described which make effective use of game play mechanics to engage students. The integration of analytics into the game to measure student retention was discussed and demonstrated. This approach potentially offers a new engaging and highly interactive way to teach engineering related material. The adapting and adopting of different media by students and young people does seem to be accelerating the creation of new spaces and landscapes of learning. For them knowledges and media are both universally accessible and globally located, and university staff need to embrace the fact that students are increasingly becoming digital and intellectual risk takers, with all the opportunities for learning that creates.

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	Constellation 1 Problem-based learning for knowledge management	Constellation 2 Problem-based learning through activity	Constellation 3 Project-led problem-based learning	Constellation 4 Problem-based learning for practical capabilities	Constellation 5 Problem-based learning for design based learning	Constellation 6 Problem-based learning for critical understanding	Constellation 7 Problem-based learning for multimodal reasoning	Constellation 8 Collaborative distributed problem-based learning	Constellation 9 Problem-based learning for transformation and social reform
Problem type	Designed to promote cognitive competence	Designed to promote learning through activity	Project-led	Practical resolution	Design-based	Knowledge with action	Managing dilemmas	Defined by team in relation to practice	Seeing alternatives
Level of interaction	Problem-focussed	Activity-focused	Project team	Practical action	Activity-focused	Integrations of knowledge/skills across boundaries	Taking a critical stance	Collaborative	Exploring structures and beliefs
Focus of knowledge	Mode 1 Propositional knowledge that is produced within academe separate from its use	Mode 2 Knowledge that transcends disciplines and is produced in, and validated through, the world of work	Mode 2 Knowledge that transcends disciplines and is produced in, and validated through, the world of work.	Mode 2 Knowledge that transcends disciplines and is produced in, and validated through, the world of work.	Mode 2 Knowledge that transcends disciplines and is produced in, and validated through, the world of work.	Mode 3 Knowing in and with uncertainty, a sense of recognising epistemological gaps that increase uncertainty	Mode 3 Knowing in and with uncertainty, a sense of recognising epistemological gaps that increase uncertainty	Mode 4 Disregarded knowledge, spaces in which uncertainty and gaps are recognised	Mode 4 and 5 Disregarded knowledge/ Holding diverse knowledges with uncertainties
Form of facilitation	Directive	Activity-focused	Project management	Guide to practice	Project management	Coordinator of knowledge and skills	Orchestrator of learning opportunities	Enabler of group reflection	Decoder of cultures
Focus of assessment	Testing of knowledge	Competence for the world of work	Project management	Competence for the world of work	Design critique and professional capabilities	Use of capabilities across contexts	Integrate capabilities across disciplines	Self analysis	Flexible and student-led
Learning emphasis	Knowledge management	Development of capabilities	Completion of project	Development of capabilities	Development of design-based capabilities	Synthesis across boundaries	Critical thought	Effective team work	Interrogation of frameworks

Table 1. Constellations of problem-based learning (Savin-Baden, 2014)

Learning Levels	Didactic approach	Problem type	Creativity facet
Level: Beginner	Scripted learning paths	Interpolation problems	Self- reflective learning
Level: Intermediate	Real world scenarios	Synthesis problems	Learning by creating something
Level: Advanced	Research based learning	Dialectic problems	Reach for original ideas

Table 2 Three consecutive learning levels, corresponding to the problem types and three facets of creativity

Table 3 Forms of knowledge and problems for PBL

Explanatory knowledge	Descriptive knowledge	Procedural knowledge	Personal knowledge
<p><i>Types of problems</i></p> <p>Explanation problem</p> <p><i>Examples</i> People in the fifteenth century used to believe it was possible to fall off the edge of the known world <i>Example of question</i></p> <p>Explain why</p>	<p>Fact-finding problem</p> <p>Following recent political changes relating to land use in Zimbabwe many internal borders have changed</p> <p>What would a legal map look like?</p>	<p>Strategy problem</p> <p>A 43-year-old woman cannot lift her right arm more than 45 degrees and she complains of pins and needles in her hand</p> <p>If you were this client's physio- therapist what would you do?</p>	<p>Moral dilemma problem</p> <p>A mother breaks into a chemist's shop at night to obtain life-saving drugs for her baby. She contacts her local physician the next day to explain what she has done</p> <p>What should the doctor do?</p>

Adapted from Schmidt and Moust (2000)

Table 4 Problem-based Learning and Game-based Learning

Approach to Learning	Type of problem	Forms of knowledge	Related theory	Exemplars	Role of Student	Role of tutor
Problem-based learning	Open ended situations and problems	Contingent and constructed	Critical pedagogy and social action	Savin-Baden (2000)	Active participant and independent critical inquirer who owns their own learning experience	Enabler of opportunities for learning
Game-based Learning	Step-by-step logical problem-solving through knowledge supplied by lecturer.	Propositional and practical	Cognitive learning theories	Arnab et al, 2015	Problem-solver who acquires knowledge through game-based problem-solving	Guide to the right knowledge and solution
Game-based Problem-based Learning	Open ended problem-based game	Contingent: spaces in which uncertainty and gaps are recognised	Critical pedagogy and Transformative learning	Callaghan et al 2013 Lameras, and Savin-Baden. (2014)	Creative explorer	Orchestrator of opportunities

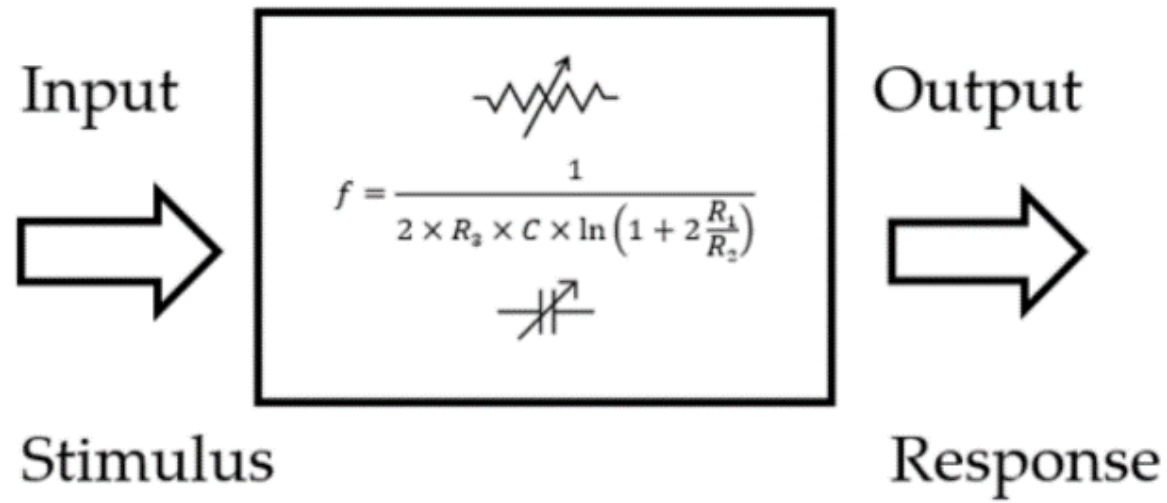


Figure 1 Core game loop for Circuit Warz project

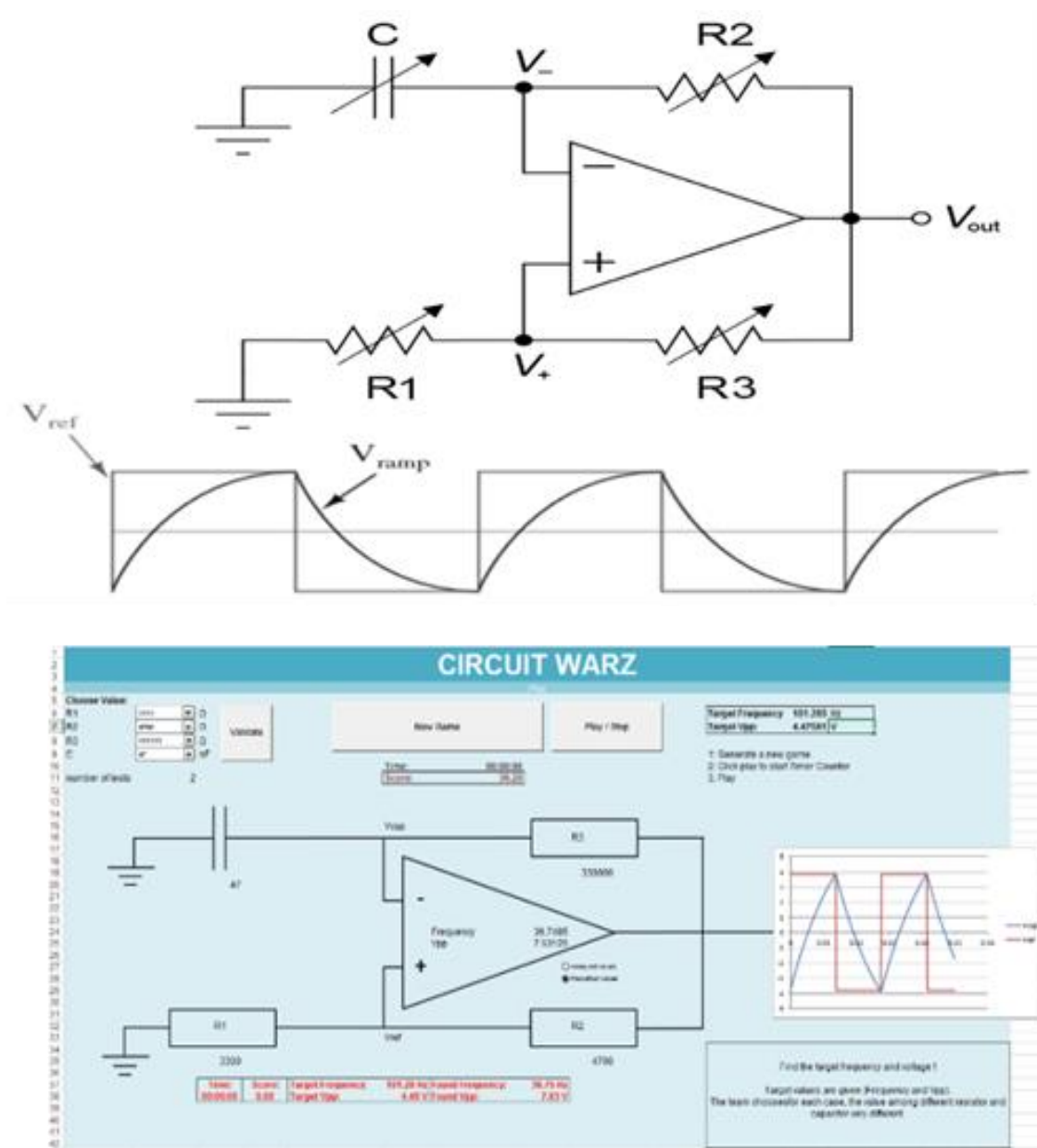


Figure 2 Solve for R1, R2, R3, C to achieve target frequency and Vpp

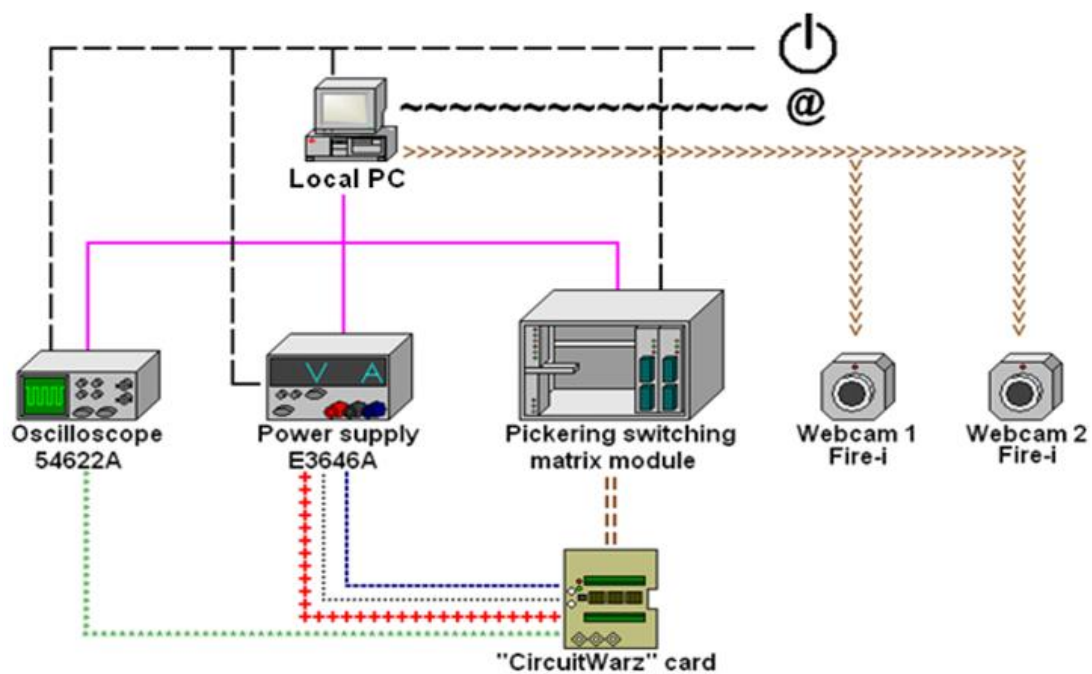


Figure 3 Architecture of the physical hardware

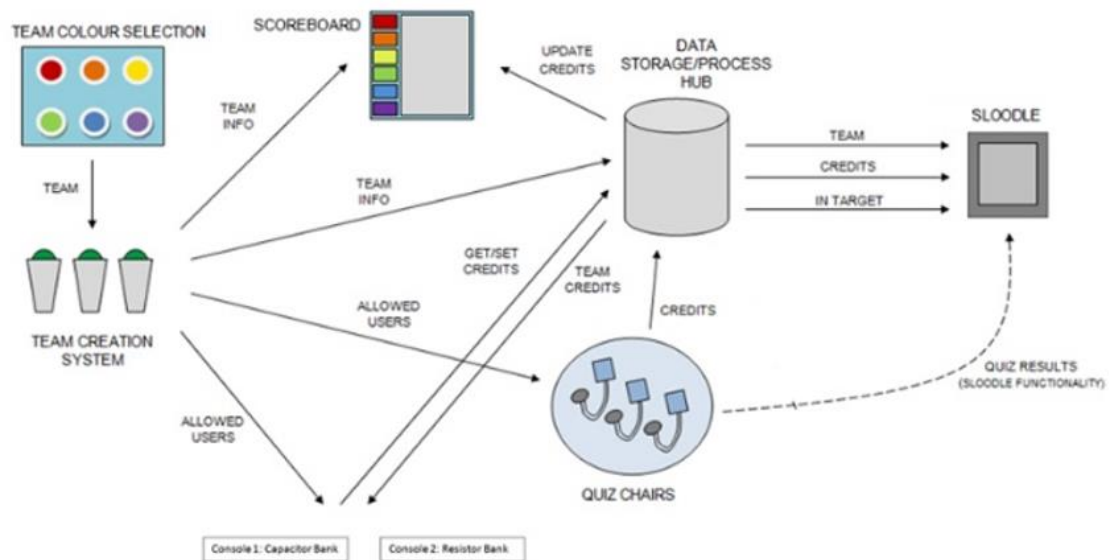
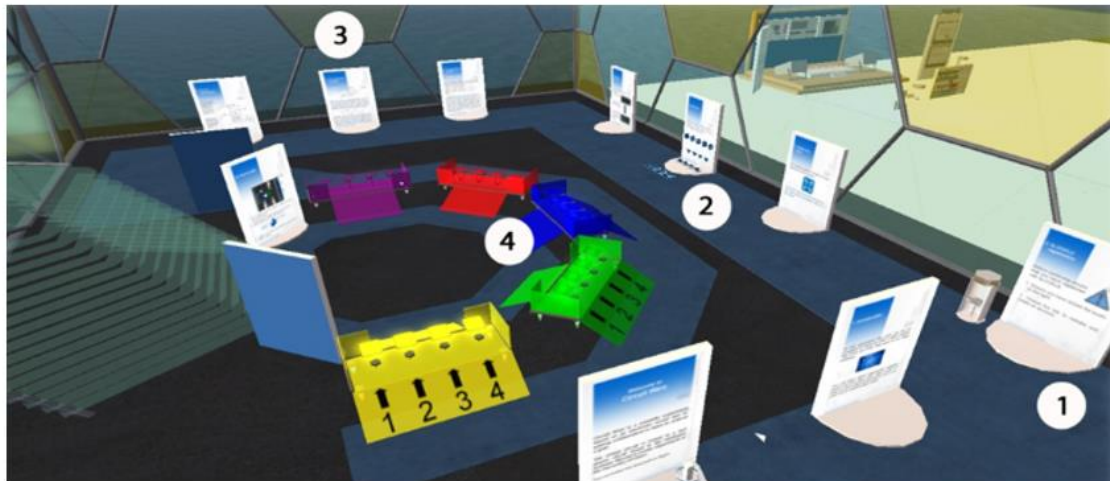


Figure 4 Learning zone and user/system management functionality

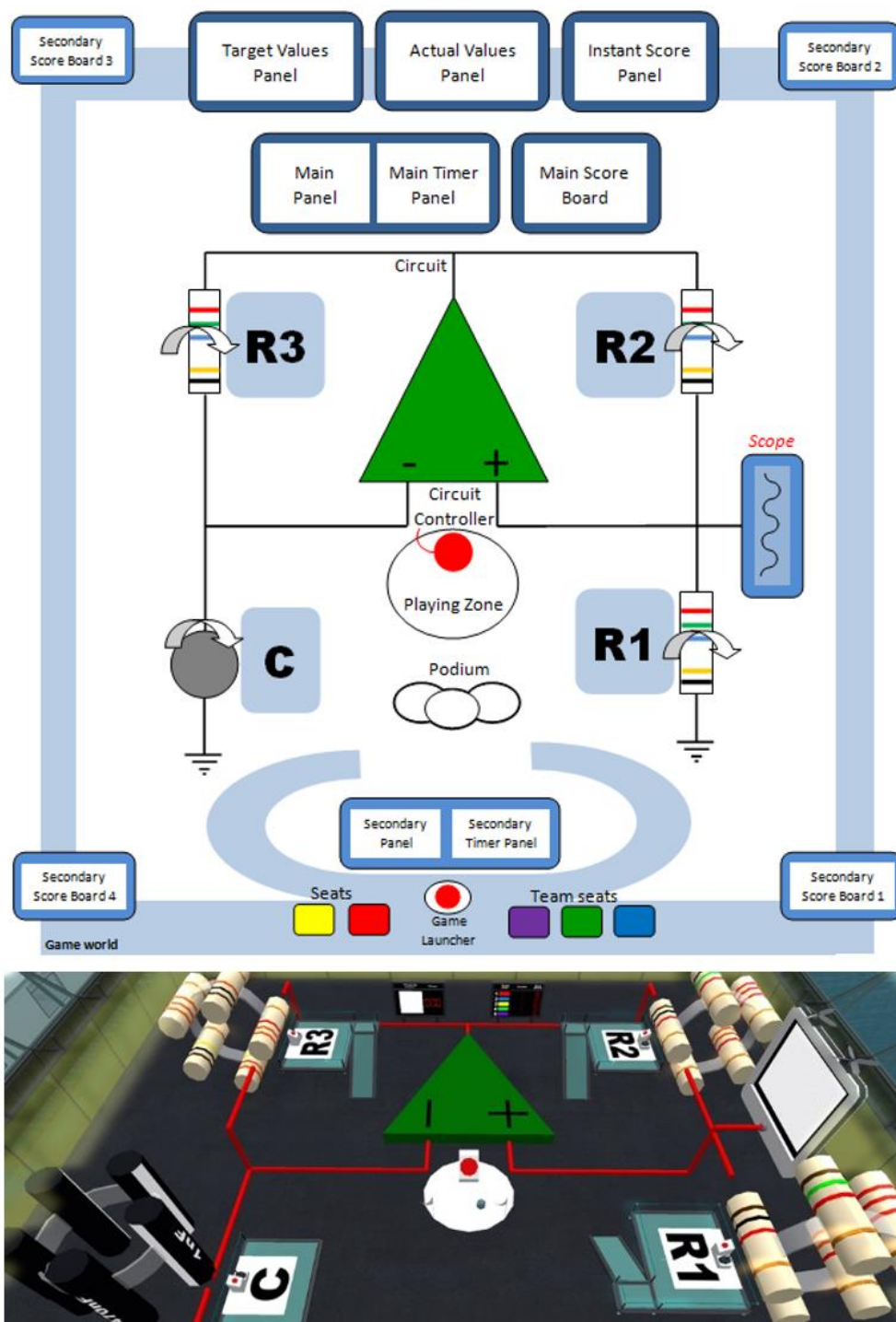


Figure 5 Overview of game arena functionality and implementation in Second Life

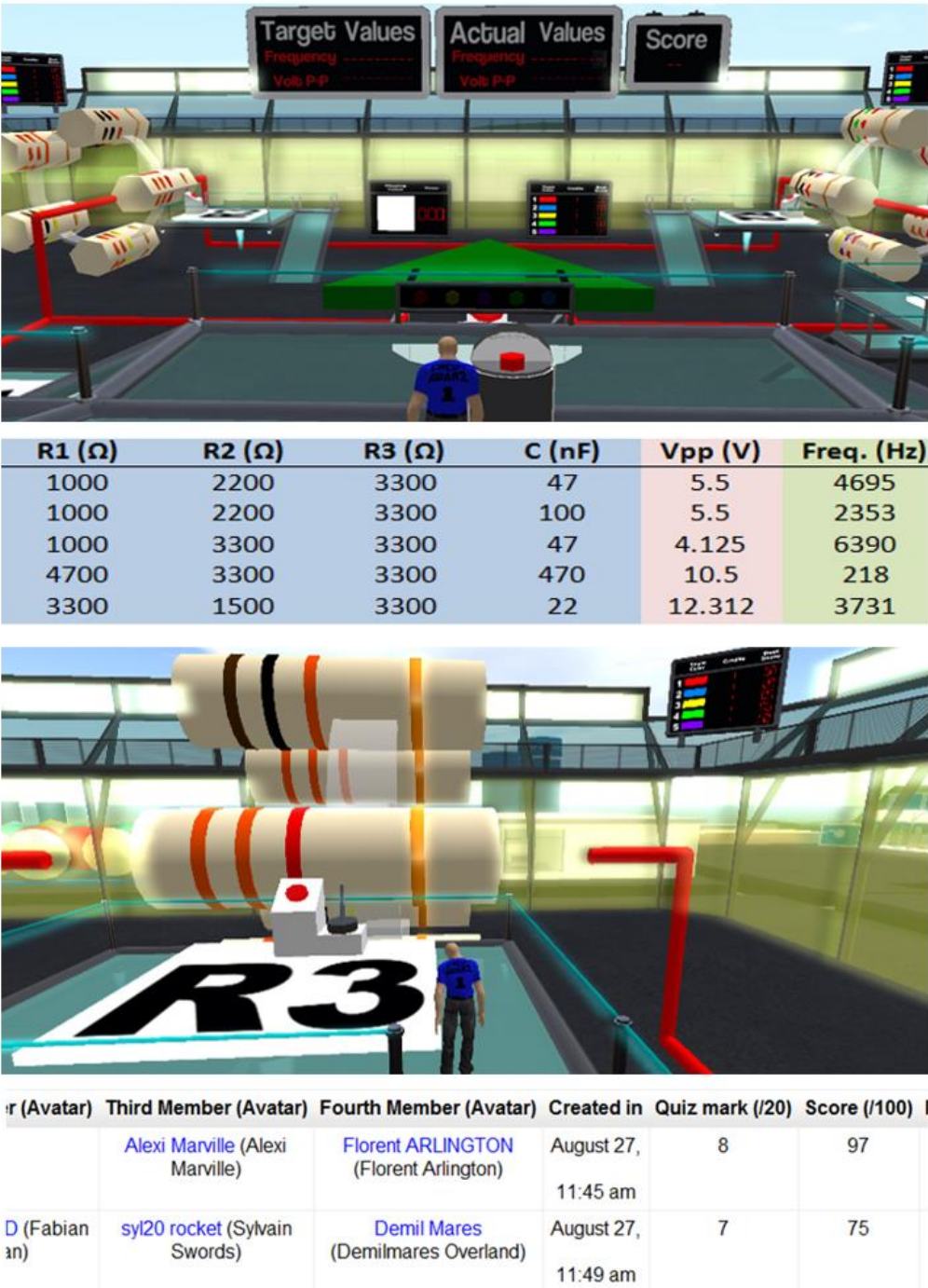


Figure 6 Game play arena, resistor/capacitor combinations/outputs and score in VLE

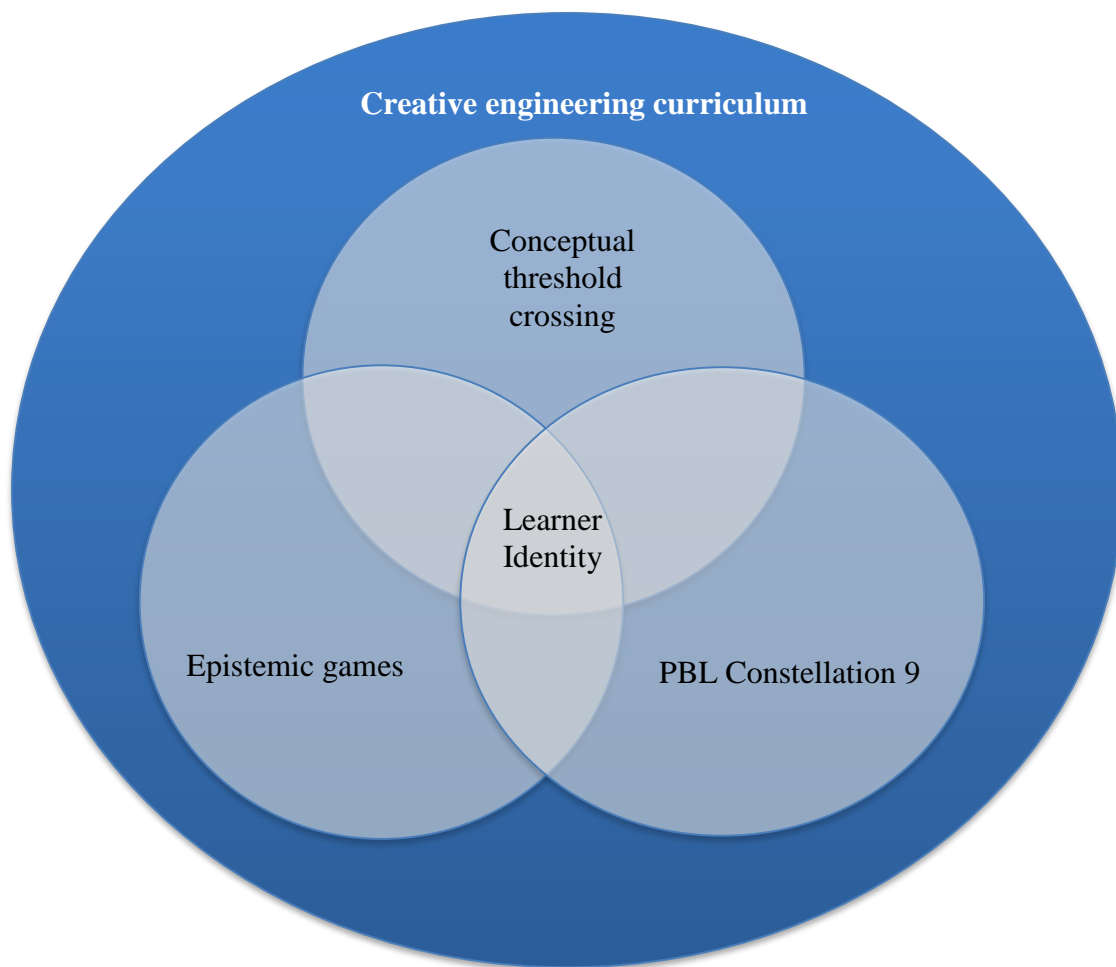


Figure 7 Creating a creative engineering curriculum